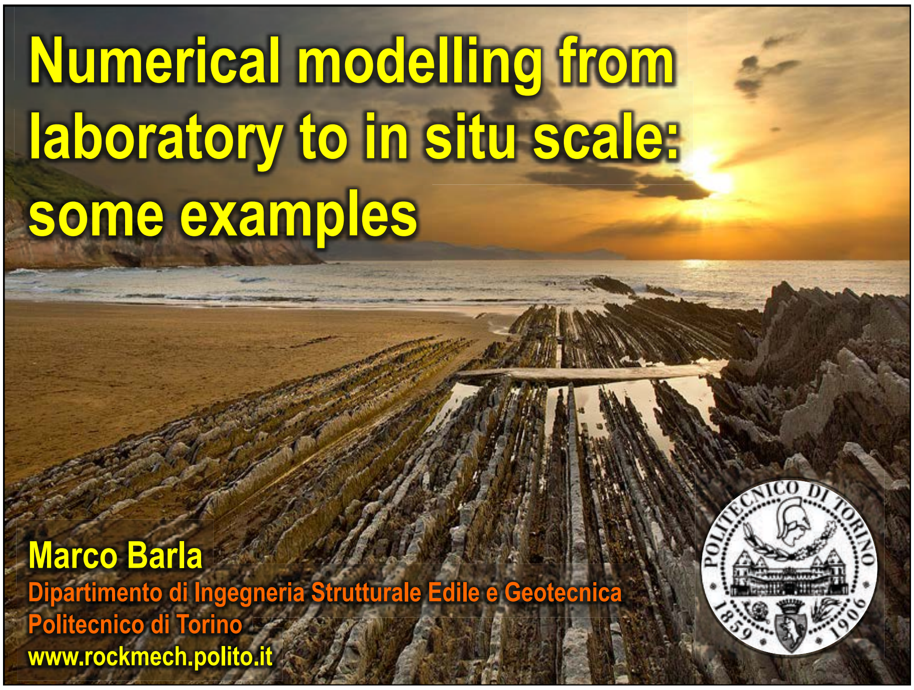
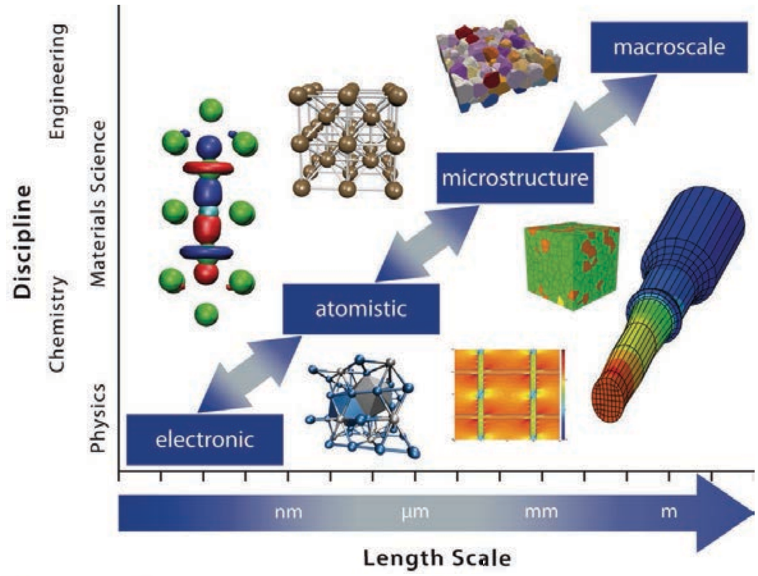


Numerical modelling from laboratory to in situ scale: some examples

Marco Barla
Dipartimento di Ingegneria Strutturale Edile e Geotecnica
Politecnico di Torino
www.rockmech.polito.it

Outline

- Multi scale approach
- Example 1: Modelling randomly cemented alluvial deposit (DEM)
- Example 2: Tunnelling in squeezing conditions (FDM)
- Example 3: Rock slope stability problem (FDEM)
- Final remarks

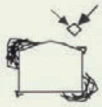


Multi-scale approach

Numerical modelling in rock engineering

CONTINUUM

- SOILS
- SOFT ROCKS
- MASSIVE ROCK MASSES

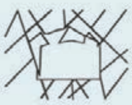


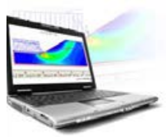
EQUIVALENT CONTINUUM

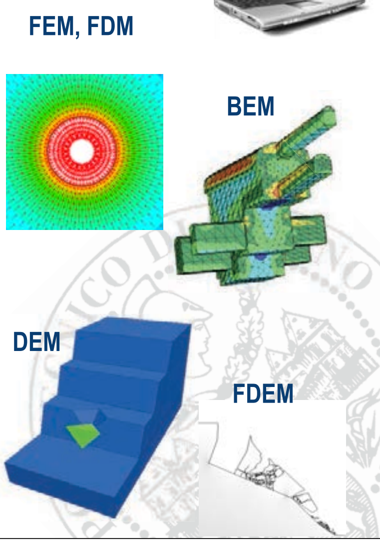
- HEAVILY JOINTED ROCK MASSES

DISCONTINUUM

- JOINTED ROCK MASSES







Numerical modelling in rock engineering

Numerical analyses can be conducted in 2D or 3D conditions and can be adopted to solve diverse rock engineering problems.

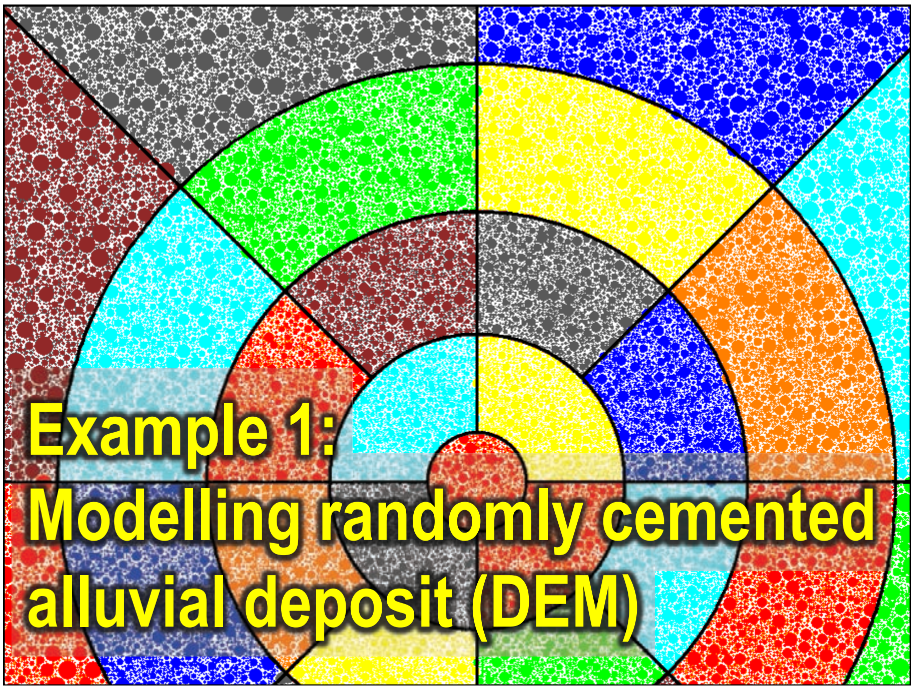
The choice on the method to be adopted is crucial and depends on the problem itself, on its complexity and on the available knowledge on rock mass conditions and properties, e.g. the:

- in situ stress state,
- degree of fracturing of the rock mass,
- geometric ratio between REV and the characteristic dimensions of the engineering problem.

Numerical modelling in rock engineering

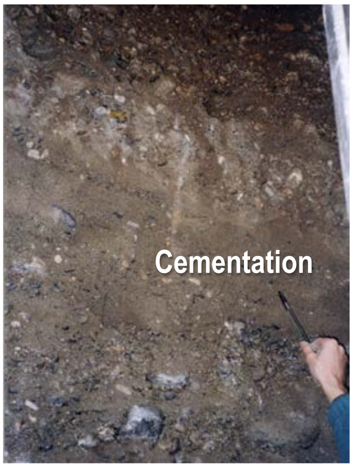
For problems in which **large-scale phenomena are strongly influenced by processes occurring at much smaller scales** (e.g. fracture propagation), executing exhaustive simulations including the processes at the smallest scales for a domain of engineering significance, **is currently impractical**, and likely to remain so for a very long time.

Numerical methods may be used with a **multi-scale approach** combining multiple models defined at fundamentally different length scales within the same overall spatial domain. For example, a small-scale model with high resolution can be used in a fraction of the overall domain and linked to a large-scale model with coarse resolution over the remainder of the overall domain, providing necessary efficiency of characterization and computation that **will render solution of these problems practical**.



Example 1: Modelling randomly cemented alluvial deposit (DEM)

Randomly cemented alluvial deposits



Torino subsoil

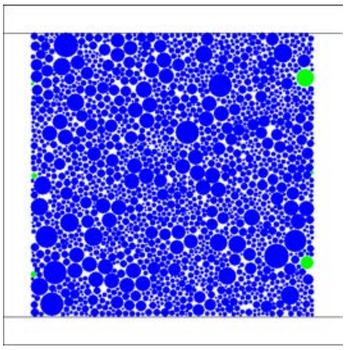
- Gravel, cobbles and sand in sandy-silty matrix (surface horizon, 25÷50 m).
- Random distribution of cementation due to calcareous deposition.
- Horizontal layers from few centimeters to meters.

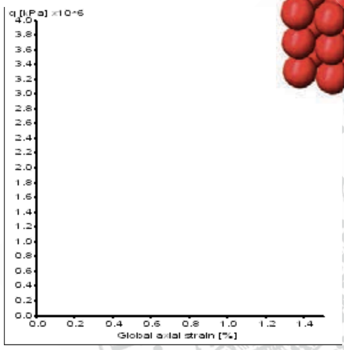
How to model heterogeneity?

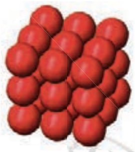
How to model spatial variability?

Heterogeneity (DEM)

Particle element modelling. Calibration of micro parameters by simulating compression loading tests on fully cemented specimen (C%=100%) and loose (C%=0).

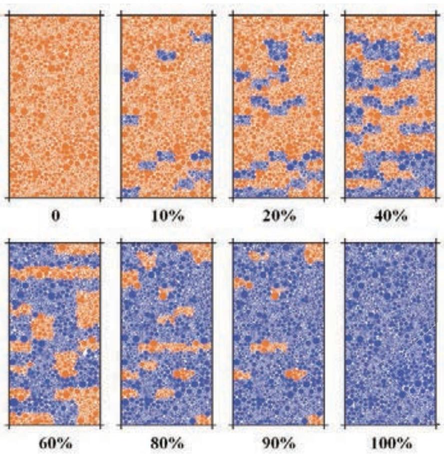


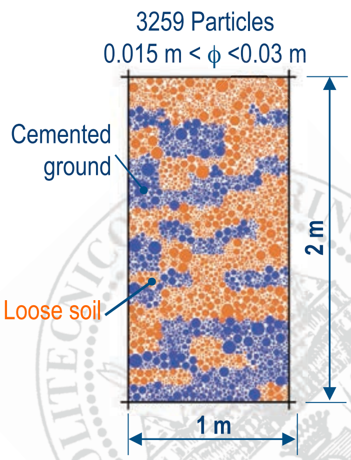




(*Camusso & Barla 2009*, *Barla & Barla 2013*)

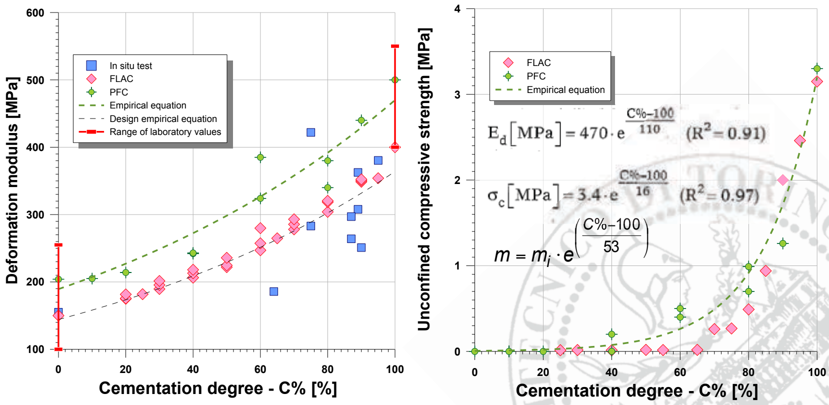
Heterogeneity (DEM)





Heterogeneity (DEM)

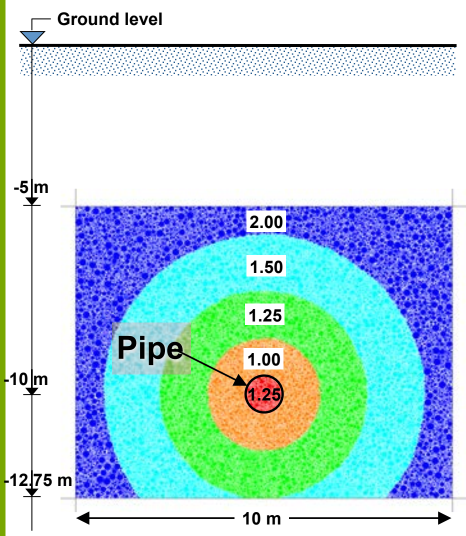
Deformability and strength parameters as a function of C%



➡ **Equivalent continuum modelling**

(Barla & Barla 2013)

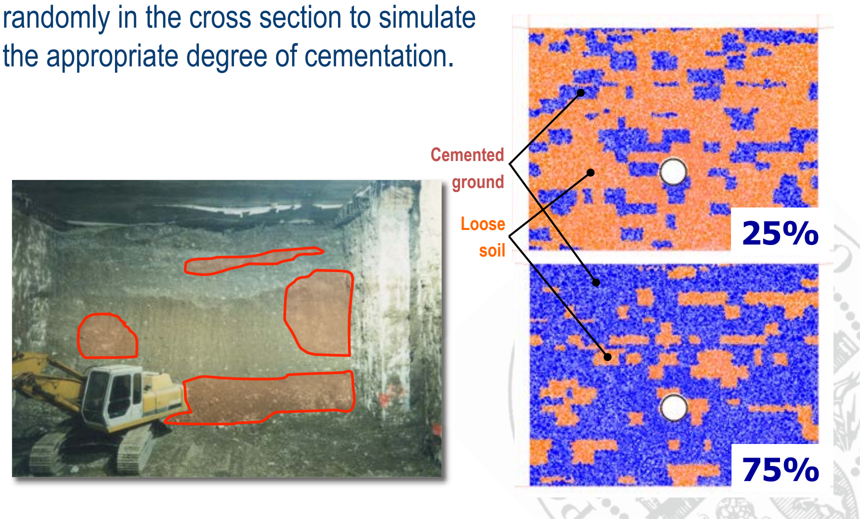
Spatial variability (DEM)



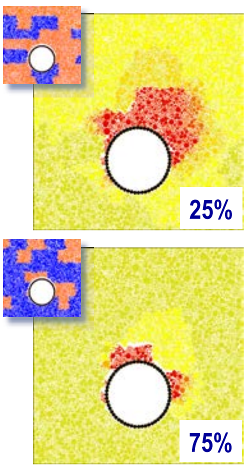
- The model reproduce a cross section, perpendicular to microtunnelling axis (soil response radial to microtunnel contour)
- The excavation of 1 m diameter microtunnel is simulated at a depth of 10 m below the ground surface
- Size: 10 x 7.75 m
- n° of particles: ~ 60,000
- **Concentric upscaling** of particles radius to optimise memory and time requirements (Konietzky et al., 2001)

Spatial variability (DEM)

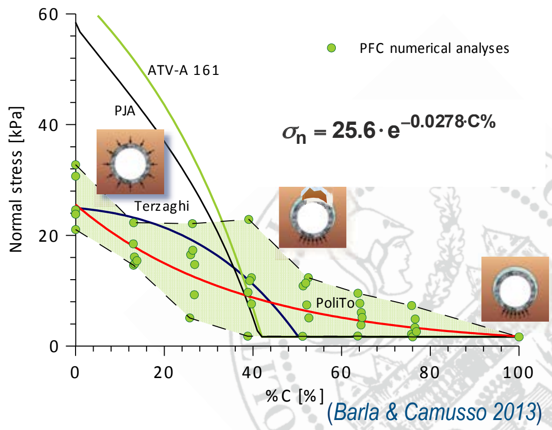
Cemented areas are reproduced randomly in the cross section to simulate the appropriate degree of cementation.



Spatial variability (DEM)



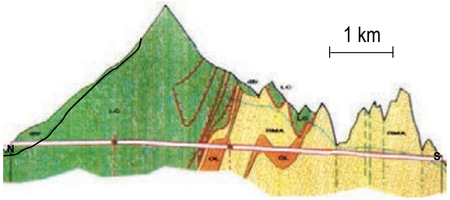
Normal stress built up as a function of C%



(Barla & Camusso 2013)

- Ground heterogeneity was studied by a small scale model for geotechnical characterisation purposes.
- Results can be used for continuum equivalent large scale models.
- Spatial variability at the large scale was included with DEM modelling (+ upscaling) to obtain more realistic ground behaviour.

Raticosa tunnel



Sedimentation and erosion caused high over consolidation of the clay materials. Tectonic deformations modified the original regular layers.

Chaotic Complex Tectonised Clay Shales

Marl and clay with inclusions

Two level of complexity

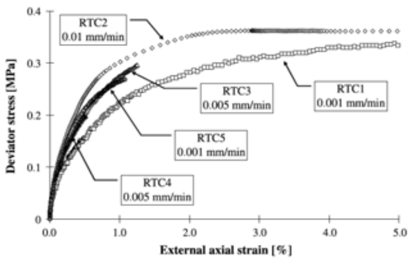
At decimetric scale (lab) = fissures and texture iso-oriented scales.

At metric scale (in situ) = the structure is chaotic with inclusions.

(*Barla et al. 2005; Bonini et al. 2009*)

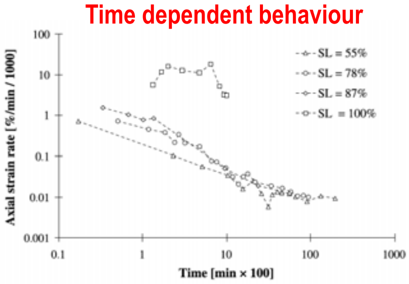
Laboratory scale

Triaxial testing results on clay shales

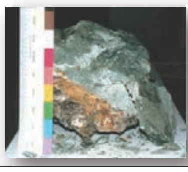


Isotropic elasto plastic constitutive law with Mohr-Coulomb failure envelope

Time dependent behaviour

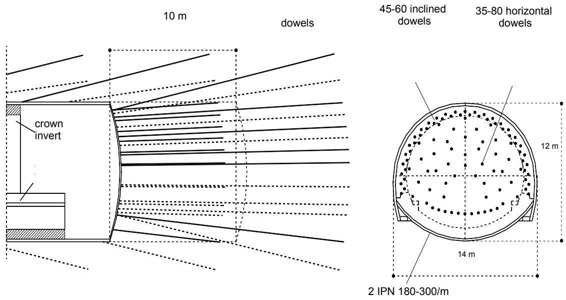


Axial strain rate versus time obtained for different stress levels (SL)

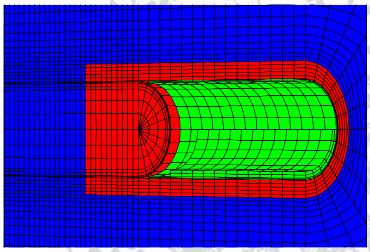


(*Bonini 2003*)

In situ scale



Full face excavation, ADECO-RS method



3D FDM numerical model
Lab data are scaled based on GSI

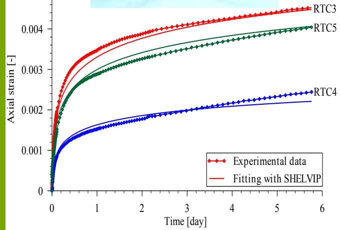
The numerical model allows to reproduce the tunnel short term behaviour but not that in the long term if the time dependent component is not included.

In situ scale

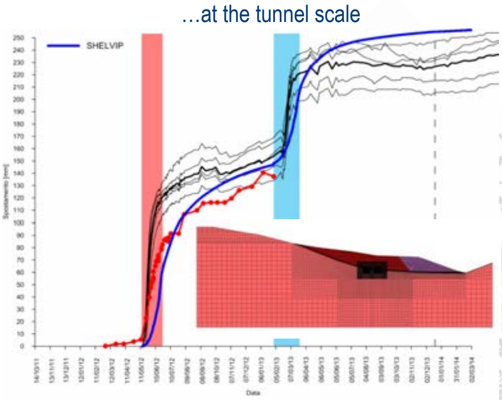
Comparison between monitoring data and computed results.

Application of time dependent constitutive models allow to simulate long term behaviour. Time dependent parameters were not scaled from lab to in situ scales.

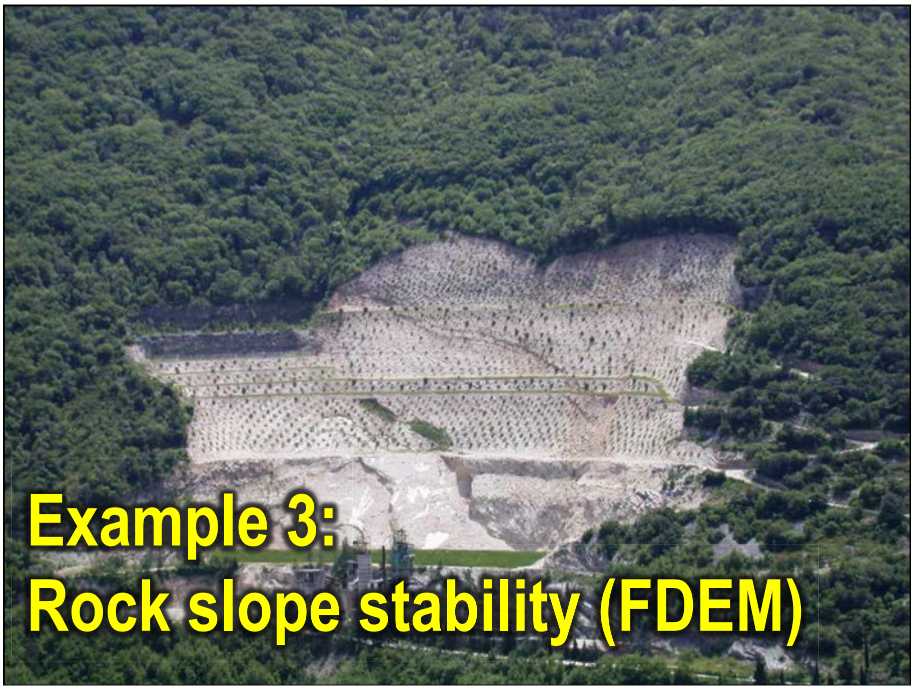
…at the laboratory scale



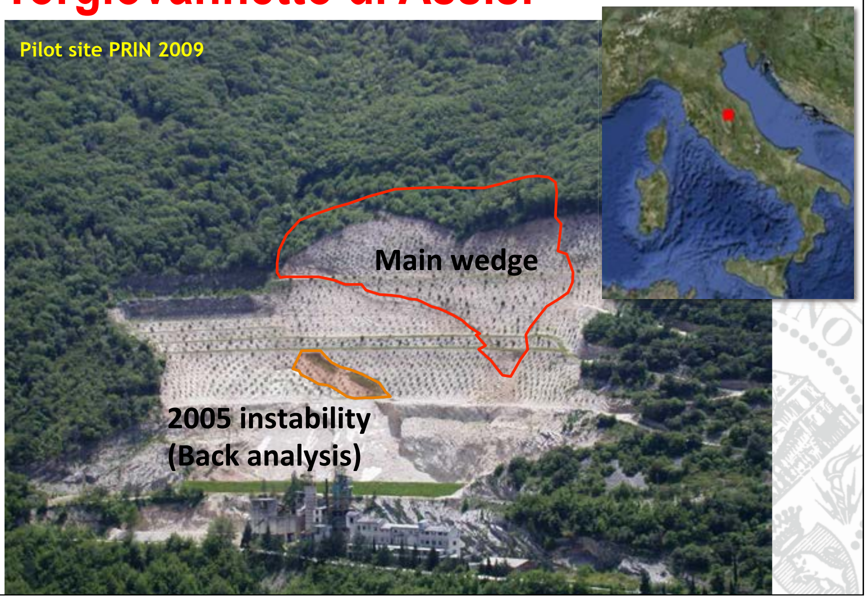
…at the tunnel scale



- Numerical models were conducted both at laboratory and tunnel scale with FDM.
- The need to scale parameters from small to large scale is not a general rule. In this example, deformability and strength parameters needed to be scaled while time dependent parameters not.
- High quality monitoring data are essential to guide the scaling process and link the models at different scales.



Torgiovannetto di Assisi

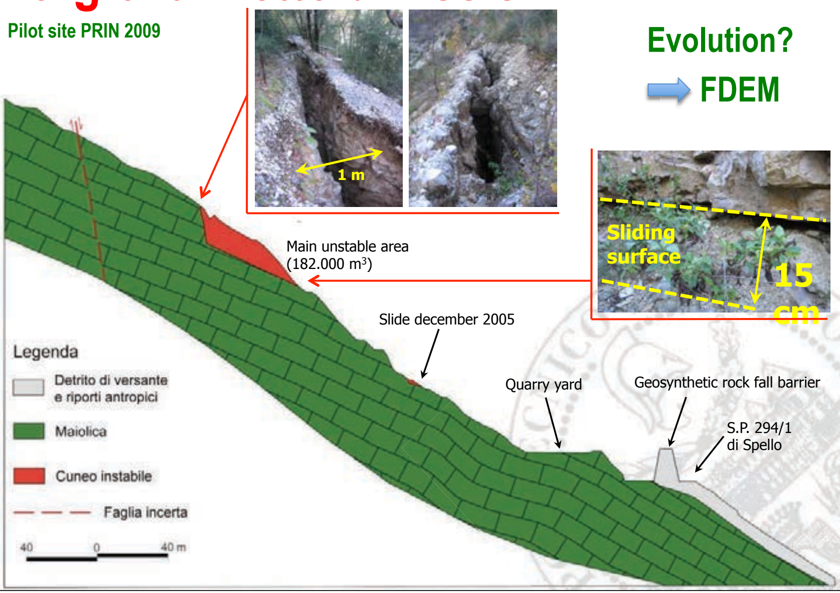


Torgiovannetto di Assisi

Pilot site PRIN 2009

Evolution?

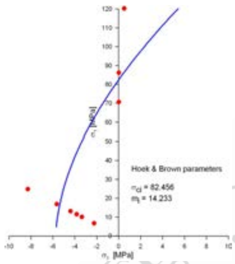
FDEM



Geotechnical caracterisation

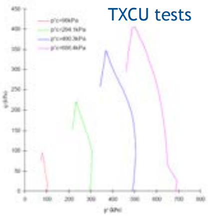
Maiolica: cretaceous flysch constituted by micritic limestone (0.2 – 2.0 m) with interbedded clay layers (up to 0.4 m).

Intact rock:
σ_{ci} = 82.5 MPa
σ_{ti} = 6 MPa
E_s = 92.5 GPa
ρ = 26.4 kN/m^3
m_i = 14.2



Interbedded clay layers:
φ' = 19.6°
c' =21 kPa

TXCU tests

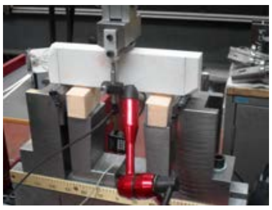


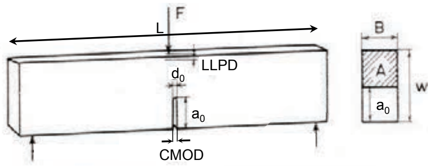
(from Ribacchi et al., 2005 and 2006; Graziani et al. 2009, Antolini 2014)

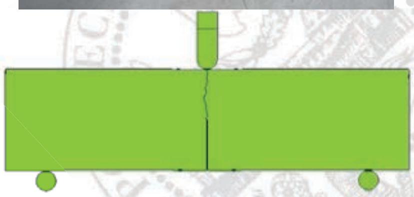
Laboratory scale

Three point bending test on Single End Notched Beam (SENB)

Determination of fracture energy (G_f)



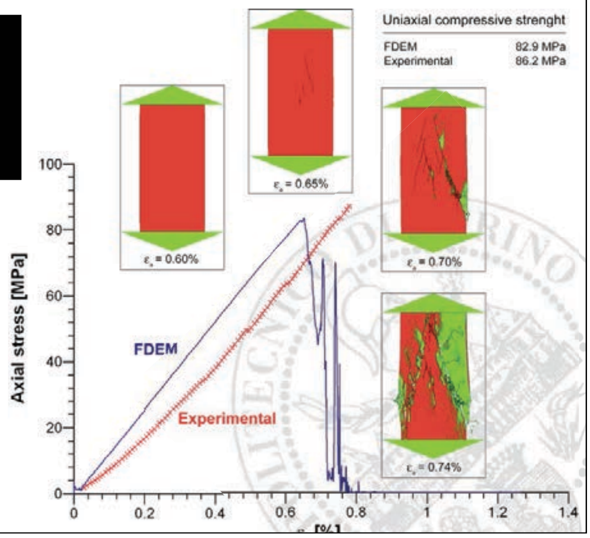




Laboratory scale

Uniaxial compression tests (UCS)

Experimental
vs FDEM



In situ scale

December 2005 collapse back analyses

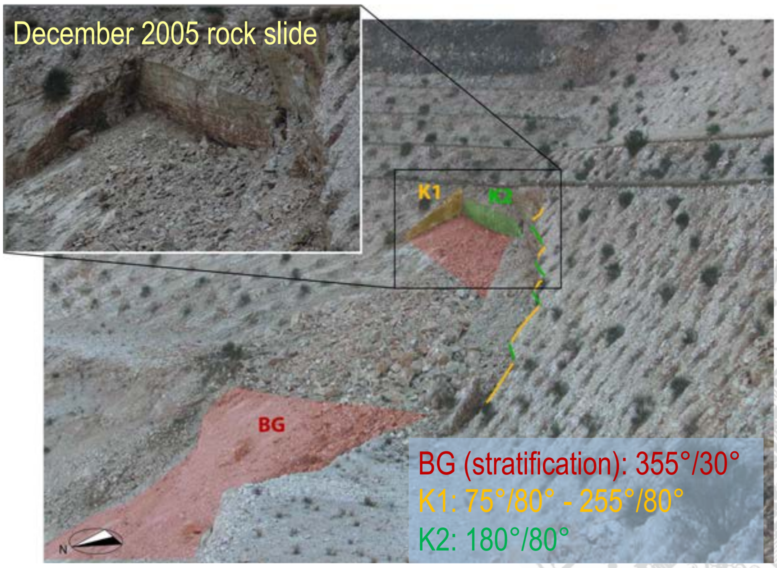
Verification through back analysis

Triggering and Scenario analysis

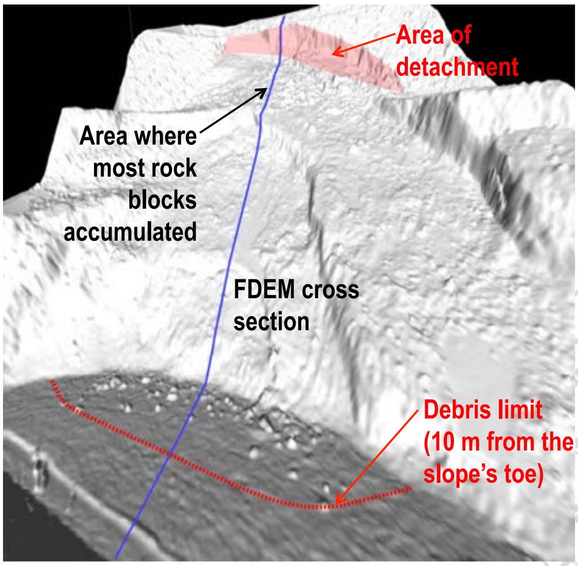
Study of triggering and runout of the 182000 m^3 unstable wedge

(Antolini 2014)

Back analysis

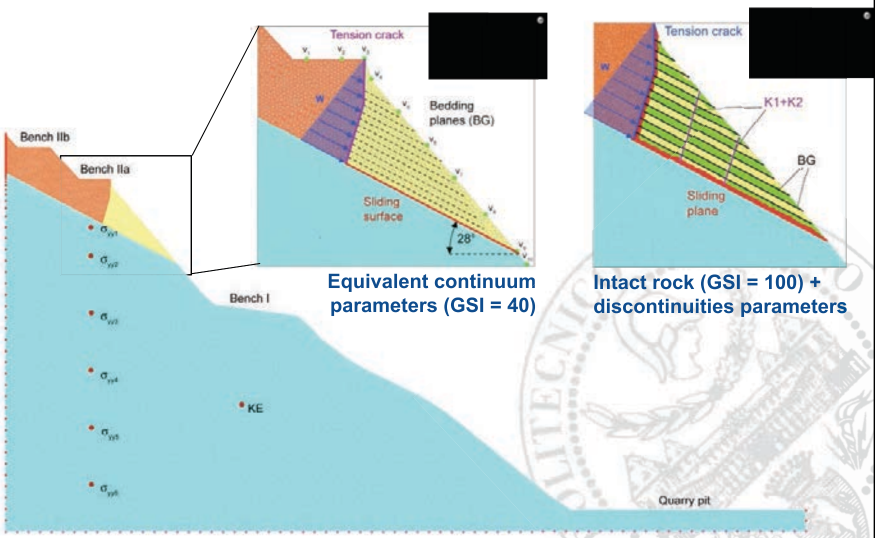


Back analysis



Laser scanner digital model made after the 2005 rock slide.

Back analysis

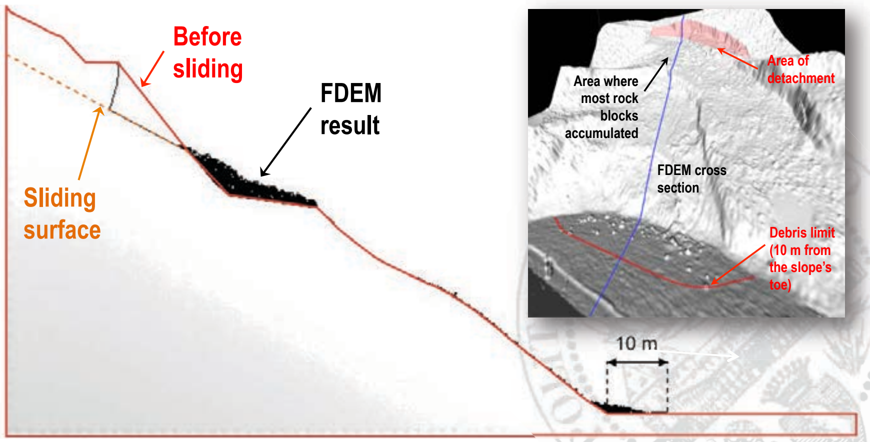


Equivalent continuum parameters (GSI = 40)

Intact rock (GSI = 100) + discontinuities parameters

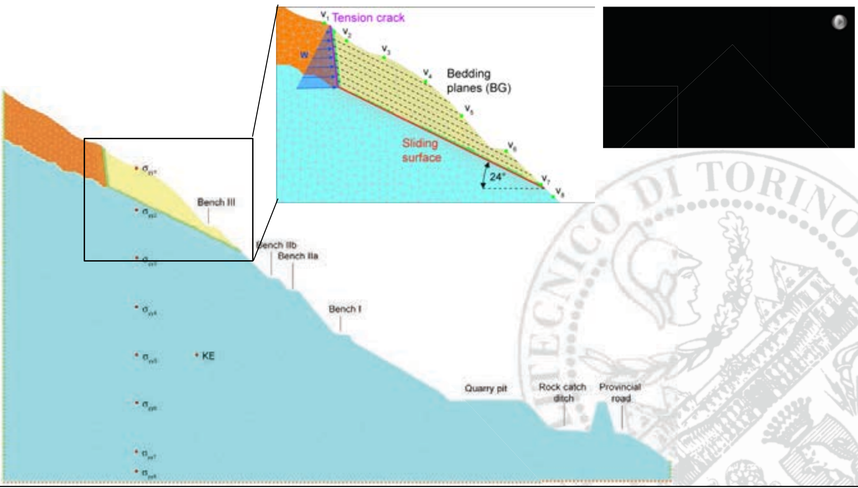
Back analysis

- The geometry of the accumulated blocks and the propagation distance on the quarry yard well reproduce observations.
- The validated parameters can be adopted for the scenario analysis.



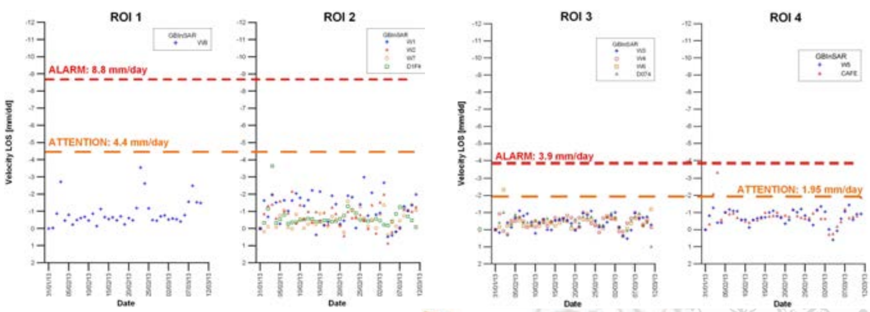
In situ scale

FDEM model of the collapse of the whole unstable wedge

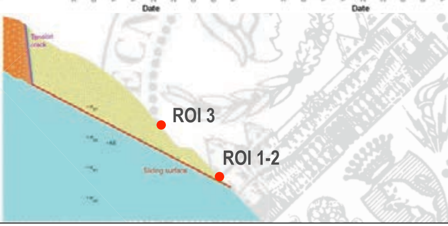


In situ scale

Thresholds can be determined for specific locations along the slope.



Example of comparison to monitoring data for this Early Warning System.



- Numerical models were conducted both at the laboratory and in situ scale with FDEM.
- Continuum equivalent as well as discontinuum modelling approach were adressed.
- Back analysis are essential for calibration and validation.

Final remarks

Three examples were considered to show that:

- Numerical methods may be used with a multi-scale approach combining models defined at fundamentally different length scales within the same overall spatial domain to render **possible** the solution for practical engineering problems in which **large-scale phenomena are strongly influenced by processes occurring at much smaller scales** (still time consuming though!).
- Multi scale approach may allow to simulate ground **heterogeneity** and **spatial variability**.
- Links between behaviors at the small and large scale have to be defined (e.g. the need to scale parameters from small to large scale is not a general rule)
- **Back analysis** and high quality monitoring data are essential in this process for calibration and validation.

References

EXAMPLE 1

Marco Camusso, Marco Barla 2009. Microparameters Calibration for Loose and Cemented Soil When Using Particle Methods. International Journal of Geomechanics 9, No. 5, 217–230.

Marco Barla, Giovanni Barla 2012. Torino subsoil characterisation by combining site investigations and numerical modelling. Geomechanics and tunnelling 5/3.

Marco Barla, Marco Camusso 2013. A method to design microtunnelling installations in randomly cemented Torino alluvial soil. Tunnelling and Underground Space Technology, Volume 33, 73-81

EXAMPLE 2

M. Bonini, D. Debernardi, M. Barla, G. Barla 2007. The Mechanical Behaviour of Clay Shales and Implications on the Design of Tunnels. Rock Mech. Rock Engng.

References

EXAMPLE 3

Marco Barla, Giovanna Piovano, Giovanni Grasselli 2012. Rock Slide Simulation with the Combined Finite Discrete Element Method. International Journal of Geomechanics 12(6).

Atzeni, Barla, Pieraccini, Antolini 2014. Early warning monitoring of natural and engineered slopes with Ground-Based Synthetic Aperture Radar . Rock Mechanics & Rock Engineering.

Also available open access online at: www.rockmech.polito.it/download

ADDITIONAL REFERENCE

Marco Barla 2010. Elementi di meccanica e ingegneria delle rocce, Celid.